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ADDITIONS TO THE VASCULAR FLORA OF WASHINGTON FROM A BIODIVERSITY STUDY ON THE HANFORD NUCLEAR RESERVATION

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Abstract

During a three-year botanical inventory of the Hanford Nuclear Reservation in south-central Washington, we located three previously undescribed entities (*Astragalus conjunctus* S. Watson var. *rickardii* Welsh, K.A. Beck, and Caplow, *Eriogonum codium* Reveal, Caplow, and K.A. Beck, and *Physaria douglasii* (S. Watson) O'Kane and Al-Shehbaz subsp. *tuplashensis* (Rollins, K.A. Beck, and Caplow) O'Kane and Al-Shehbaz, four species new to Washington (*Cistanthe rosea* (S.Watson) Hershk., *Gilia leptomeria* A. Gray, *Loeflingia squarrosa* Nutt., and *Myosurus clavicaulis* M.E. Peck), and one previously described species that had generally gone unnoticed by the American botanical community (*Festuca washingtonica* E.B. Alexeev). The botanical inventory was a part of the Hanford Biodiversity Project, which was funded by the Department of Energy and administered by The Nature Conservancy of Washington.

Key Words: Hanford Nuclear Reservation, *Astragalus conjunctus* var. *rickardii*, *Eriogonum codium*, *Physaria douglasii* subsp. *tuplashensis*, *Cistanthe rosea*, *Gilia leptomeria*, *Loeflingia squarrosa*, *Myosurus clavicaulis*, *Festuca washingtonica*.

The 1450 km^2 Hanford Nuclear Reservation (Hanford Site) is located in Benton, Grant, and Franklin Counties in south-central Washington (Fig. 1). It was acquired in 1943 by the U.S. Government for the production of weapons-grade plutonium, and it has been administered by the U.S. Department of Energy (DOE), or its predecessors. Portions of the Hanford Site have also been administered by the U.S. Fish and Wildlife Service (FWS) and the Washington State Department of Wildlife. The majority of the Hanford Site has been closed to the public and to grazing and agriculture since 1943.

In the last two decades, the mission of the Hanford Site has changed to nuclear waste clean-up, environmental restoration, research and development. In 1992, the DOE and The Nature Conservancy of Washington (TNC) entered into a Memorandum of Understanding that called for a cooperative and coordinated inventory of plants, animals, and ecologically significant areas of the Hanford Site. The Hanford Biodiversity Project began in 1994 and continued through 1998 (Soll et al. 1999). The authors conducted the botanical portion of the Biodiversity Project from 1994 through 1997. A description of previous botanical work and a checklist of vascular plant collections from the Hanford Site is in Sackschewsky and Downs (2001).

In 1999, the Hanford Reach of the Columbia River was designated a Wild and Scenic River. In 2000, President Clinton declared 78,780 ha of the Hanford Site the "Hanford Reach National Monument" and placed administration of the National Monument under the jurisdiction of the FWS. The new Monument includes the Hanford Reach of the Columbia River, the lands north of the Columbia River, and the 31,080 ha Fitzner-Eberhardt Arid Lands Ecology Reserve (ALE) (Fig. 1).

The goal of this paper is to summarize the botanical portion of the Biodiversity Project focusing on the most significant findings. The Hanford Site is a unique area from both a biogeographical and historical perspective. It supports unusual plant assemblages, many rare plant species, and a high degree of endemism, due to its underlying geology, landscape setting, topography, and climate. In addition, it is the largest area in the inland Northwest to be intentionally closed to grazing, agriculture, and residential development over a period during which human activity drastically altered much of the inland Northwest.

Study Area

The Hanford Site is located within the Columbia Basin Ecoregion, an area that historically included over 6 million ha of steppe and shrub-steppe vegetation across most of central and southeastern Washington State, as well as portions of north-central Oregon (Franklin and Dyrness 1973). The Columbia Basin Ecoregion consists primarily of shrubs, perennial bunch-

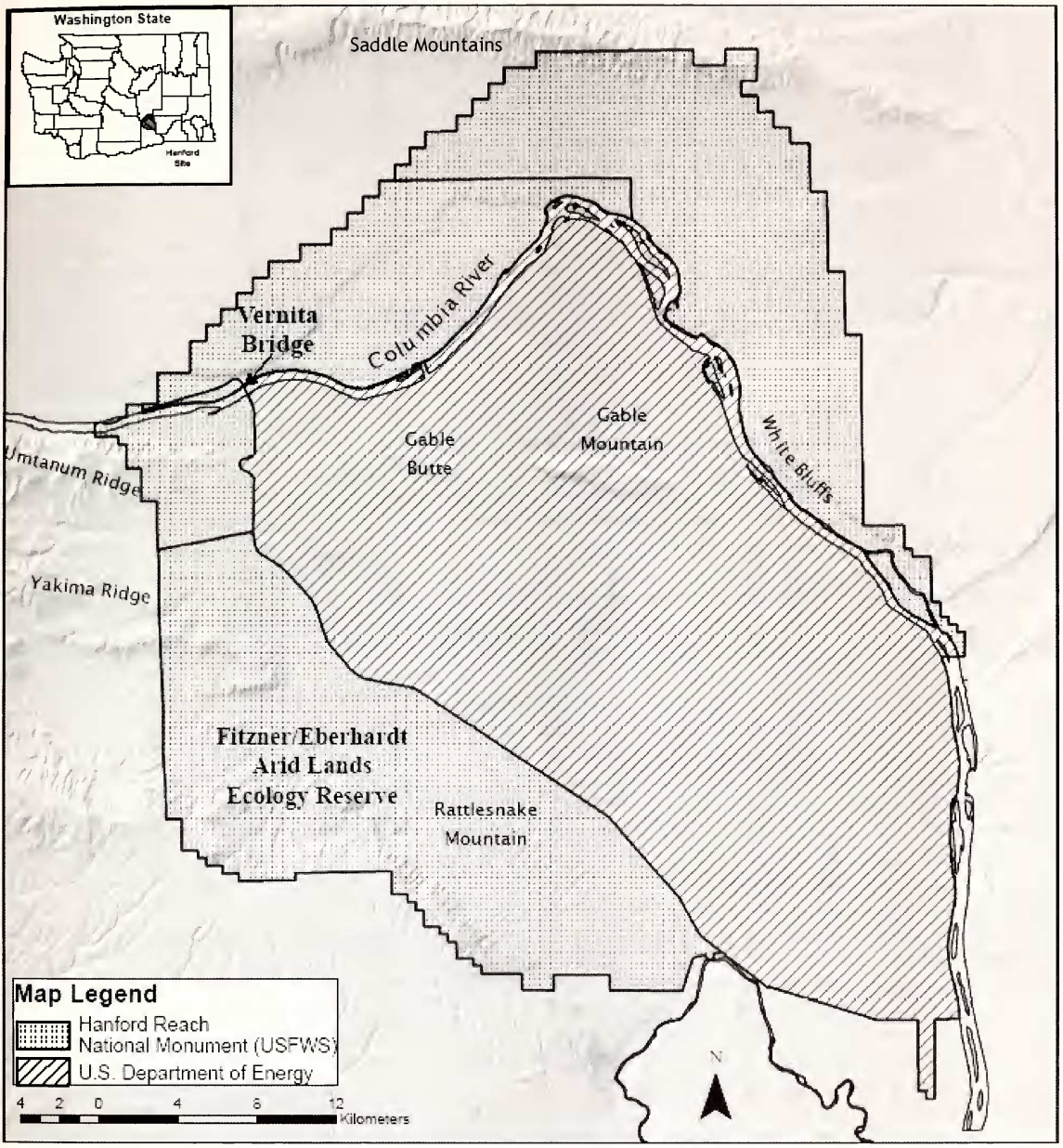

FIG. 1. Hanford Site (Benton, Grant, and Franklin counties, Washington): management areas and major topographic features.

grasses and a variety of forbs (Franklin and Dyrness 1973). It has undergone substantial loss and degradation in the post-European era due to intensive livestock grazing, introduction of invasive non-native plants, the advent of dryland wheat farming and irrigated agriculture, and altered fire regimes. Because the Hanford Site has been closed to all agricultural activities, including grazing, for nearly sixty years, its shrub-steppe plant ecosystem has been preserved in a condition and to an extent, that exists nowhere else (Soll et al. 1999). The Hanford Site supports many areas of high quality plant communities. The plant community portion of the Biodiversity Project identified 48 high quality occurrences of 17 terrestrial plant community types, and 6 high quality riparian wetland communities (Soll et al. 1999).

The Hanford Site is within the Central Basin climatological region, which is the hottest and driest climatological region in Washington. Average annual precipitation ranges from 35 cm at the summit of Rattlesnake Mountain to 16 cm near the Columbia River (Downs et al. 1993).

The Hanford Site is topographically variable (Fig. 1). Elevations within the Hanford Site range from 110 m along the Columbia River to 1100 m at the crest of Rattlesnake Mountain. Adjacent to the east side of the river are the steep bluffs of the Ringold Formation (the White Bluffs), which rise in places to over 185 m above the river. A number of long basalt anticlinal ridges traverse Hanford, including: Rattlesnake Mountain and the Rattlesnake Hills, Yakima Ridge, Umtanum Ridge, Saddle Mountains, and Gable Mountain. The only free-flowing section of the Columbia River in the U.S., known as the Hanford Reach, flows for 76 km from the northwest to the southeast through the northern portion of Hanford.

No perennial creeks drain to the Columbia River from the Hanford Site. Large dune fields occur on both sides of the Columbia River within the Hanford Site. The Hanford Site has a number of unique habitats and substrates, which include springs, sand dunes, vernal pools, riverine wetlands, caliche soils, basalt ridgetops, basalt-derived sand dunes, and alkaline areas.

Methods

The authors made over 15 visits to the Hanford Site between 1994 and 1997 to survey for vascular plant taxa considered rare in Washington at the time (Washington Natural Heritage Program 1994). We spent a total of 285 days in the field between late March and early September. We surveyed more than 19,000 ha. Field inventory methodology was based on habitat and flowering times of rare plant taxa potentially present in the area. The list of plants potentially present in the area was acquired from the Washington Natural Heritage Program, and the flowering times and habitat were obtained from the five-volume Vascular Plants of the Pacific Northwest (Hitchcock et al. 1955–1969). We focused inventories in areas with high quality vegetation associations, high diversity, and unusual substrates. Search intensity varied, depending on the quality of the habitat and the likelihood that the particular habitat could support rare plant populations. The lightest search intensity was a walked transect through the area, and the most intensive search intensity was a series of tightly spaced transects in which the entire area was visually examined, often several times during the growing season. A list of all plants was compiled, and specimens were deposited primarily at the University of Washington Herbarium (WTU). In some cases, taxonomic experts requested specimens, or isotypes were collected for other herbaria, and so specimens were also deposited at NY, US, WS, BRY, CAS, COLO, GH, K, MARY, MO, NY, RM, RSA, TEX, UC, and OSU. Nomenclature generally follows relevant Flora of North America treatments and the Integrated Taxonomic Information System (ITIS) database (Integrated Taxonomic Information System 2004). Existing specimens at the University of Washington Herbarium (WTU) and the Washington State Marion Ownbey Herbarium (WS) were used for comparison.

Results

We identified more than 400 species of vascular plants and numerous populations of 29 rare plants considered rare in Washington (Soll et al. 1999) during our three year inventory of the Hanford Site, of which three were previously undescribed, four were new records for the state, and one had long been ignored. These eight are the focus of this paper. The three previously undescribed entities are *Astragalus conjunctus* S. Watson var. *rickardii* S.L. Welsh, K.A. Beck and Caplow, *Eriogonum codium* Reveal, Caplow, and K.A. Beck, and *Physaria douglasii* (S. Watson) O'Kane and Al-Shehbaz subsp. *tuplashensis* (Rollins, K.A. Beck and Caplow) O'Kane and Al-Shehbaz. The three species new to Washington are *Cistanthe rosea* (S. Watson) Hershk., *Gilia leptomeria* A. Gray, *Loeflingia squarrosa* Nutt., and *Myosurus clavicaulis* M.E. Peck). The previously described species that had generally gone unnoticed by the American botanical community is *Festuca washingtonica* E.B. Alexeev). Each entity is discussed below, and the larger findings of the study are also summarized.

Previously Undescribed Entities

Astragalus conjunctus S. Watson var. *rickardii* S.L. Welsh, K.A. Beck & Caplow (Fabaceae)

The section *Conjuncti* Barneby in *Astragalus* L. is well represented in south-central Washington and north-central Oregon. *Astragalus conjunctus* S. Watson, *A. leibergii* M.E. Jones, *A. reventiformis* (Rydb.) Barneby, and *A. hoodianus* Howell all occur in this region (Barneby 1964). Although clearly belonging to the section *Conjuncti*, a number of *Astragalus* collections from Rattlesnake Mountain on the Hanford Site and from the nearby Horse Heaven Hills could not be satisfactorily assigned to any of the above species. We subsequently described a new variety, *A. conjunctus* var. *rickardii* (Welsh et al. 1997). In addition to Rattlesnake Mountain and Horse Heaven Hills, the variety is also known from northern Oregon.

The var. *rickardii* has erect, sessile, strigulose pods, campanulate to short-cylindric calyces, and a banner reflexed at about 45°. This combination of characteristics is not found in other members of the section (Welsh et al. 1997).

Astragalus conjunctus var. *rickardii* was found between 450 and 1070 m elevation in deep soil on

the upper portions of mostly north-facing slopes. It was primarily found in bunchgrass communities that are typically not currently grazed. Common associated species were *Artemisia tridentata* Nutt., *Pseudoroegneria spicata* (Pursh.) A. Löve, *Poa secunda* J. Presl., *Phlox longifolia* Nutt., *Balsamorhiza careyana* A. Gray, and *Crepis atribarba* A. Heller.

The variety is named in honor of Dr. William Rickard, a shrub-steppe ecologist and one of those responsible for the establishment of the Arid Lands Ecology Reserve. *Astragalus conjunctus* var. *rickardii* is currently included on the Watch list in Washington (Washington Natural Heritage Program 2005).

Eriogonum codium Reveal, Caplow & K.A. Beck (Polygonaceae)

During our 1995 botanical inventory of the Umtanum Ridge area of the Hanford Site we found a population of plants in the genus *Eriogonum* that did not resemble any known taxon. We subsequently published a new species, *Eriogonum codium* (Reveal et al. 1997). *Eriogonum codium*, or Umtanum desert buckwheat, is included in the subgenus *Eucycla* Nutt. The combination of cymose-umbellate inflorescences and sparsely tomentose flowers and achenes set *E. codium* apart from all other *Eucycla* taxa.

Eriognum codium forms low, shrubby mats up to 1 m in diameter, and bears yellow flowers in cymose-umbellate inflorescences atop short scapes. A single plant may have as many as 300 inflorescences. Inflorescences produce flowers from June through September. Our growth ring counts on several dead individual plants suggest potential life spans of greater than 100 years (Dunwiddie et al. 2001).

Eriogonum codium is known from one population that occurs in a discontinuous band 2.5 km long by 30 m wide. The population census in 1997 found 5200 adult plants in five small subpopulations on flat or gently sloping substrates above the steep north and northwest-facing slopes of Umtanum Ridge, at an elevation of approximately 375 m. A census of the population in 2005 found only 4418 adult plants in the population (a 15% decline in 8 years). The population was restricted to the exposed, barren basaltic flow top of the Lolo Flow, one of the many Columbia River basalt flows (Goff 1981). It was found with *Grayia spinosa* (Hook.) Moq., *Artemisia tridentata* Nutt., *Salvia dorrii* (Kellogg) Abrams, *Krascheninnikovia lanata* (Pursh) A.D.J. Meeuse & Smit, *Hesperostipa comata* (Trin. & Rupr.) Barkworth, *Poa secunda* J. Presl., *Pseudoroegneria spicata* (Pursh.) A. Löve, *Astragalus caricinus* (M.E. Jones) Barneby, *Bromus tectorum* L., *Mentzelia albicaulis* (Douglas ex Hook.) Douglas ex. Torr. & A. Gray, and *Cryptantha pterocarya* (Torr.) Greene.

In 1996, a wildfire killed 20% of the adult plants in the population. There were no signs of either fire tolerance or resprouting after the fire (Dunwiddie et al. 2001). A demographic monitoring study begun in 1997 has revealed aspects of the biology of this species that may affect its long-term viability. Despite abundant germination, only one *Eriogonum codium* seedling has survived to flowering since the commencement of studies in 1997. *Eriogonum codium* is considered Endangered in Washington (Washington Natural Heritage Program 2005), and a Candidate for federal listing under the Endangered Species Act (U.S. Fish and Wildlife Service 1999).

Physaria douglasii (S. Watson) O'Kane and Al-Shehbaz subsp. *tuplashensis* (Rollins, K.A. Beck and Caplow) O'Kane and Al-Shehbaz (Brassicaceae)

In 1883, T.S. Brandegee and F. Tweedie, who were employed as botanists for the Northern Transcontinental Survey (Rose 1904), collected a *Lesquerella* from the White Bluffs of the Columbia River. This fragmentary collection, dated July 1883, caused difficulties in a number of early treatments of *Lesquerella* (Gray and Watson 1895; Piper 1906), and was attributed to *L. douglasii* Wats. (Payson 1922; Rollins and Shaw 1973; Rollins 1993). *L. douglasii* is generally restricted to the valleys of the Kootenay and Columbia Rivers from northern Oregon to southern British Columbia (Rollins and Shaw 1973). In July of 1994, we collected flowering material from a *Lesquerella* on the White Bluffs that appeared to have both significant morphological and phenological differences from *L. douglasii*. These plants were subsequently described as a new species: *Lesquerella tuplashensis* (Rollins et al. 1996).

A recent treatment (Al Shehbaz and O'Kane 2002) has united *Lesquerella* with *Physaria* and united *L. douglasii* and *L. tuplashensis* under the single species name *Physaria douglasii* (S. Watson) O'Kane & Al-Shehbaz. *Lesquerella tuplashensis* was retained as a subspecies of *P. douglasii* and became *P. douglasii* subsp. *tuplashensis* (Rollins, K.A. Beck & Caplow) O'Kane & Al-Shehbaz, but not on the basis of new research or study of the two taxa. We are conducting morphometric and common garden experiments to further clarify the rank of this entity. At this time, ITIS still lists *Lesquerella tuplashensis* as the accepted name (ITIS 2005).

Physaria douglasii subsp. *tuplashensis* differs from *P. douglasii* subsp. *douglasii* in the following ways: the trichomes of the silique valves of *P. douglasii* subsp. *tuplashensis* are stipitate when viewed under a 10× lens, while those of *P. douglasii* subsp. *douglasii* are generally sessile and

appressed to the silique valve surface. The cauline leaves and the basal leaves of *P. douglasii* subsp. *tuplashensis* are broader and more imbricate than those of *P. douglasii* subsp. *douglasii* (Rollins et al. 1996). In addition, *P. douglasii* subsp. *tuplashensis* blooms in late May and early June and again in favorable years in late July and early August, while *P. douglasii* subsp. *douglasii* on riverine cobble on the Hanford Site blooms from late April to early May. We have never observed or collected *P. douglasii* subsp. *douglasii* in flower in late summer, nor have we seen any herbarium specimens of late summer flowering *P. douglasii* subsp. *douglasii*.

Physaria. douglasii subsp. *tuplashensis* was restricted to a narrow 17 km band on the upper portion of the White Bluffs of the Columbia River. The White Bluffs are composed of lacustrine sediments of the Ringold Formation (Newcomb 1958), capped by a cemented, highly alkaline (pH 8.4+) calcium carbonate paleosol (a "caliche" soil). Most of the population occurred on this caliche paleosol. Common associated plant species were *Grayia spinosa*, *Artemisia tridentata*, *Achnatherum contractum* (B.L. Johnson) Barkworth, *Bromus tectorum*, *Eriogonum microthecum* Nutt. var. *laxiflorum* Hook., and *Cryptantha spiculifera* (Piper) Payson.

Physaria douglasii subsp. *tuplashensis* is Threatened in Washington (Washington Natural Heritage Program 2005) and a Candidate for listing under the Endangered Species Act (U.S. Fish and Wildlife Service 1999). Both agencies list the entity as *Lesquerella tuplashensis*. "Tuplash" is the traditional Wanapum Indian name for the White Bluffs. The Wanapum tribe occupied the area of the White Bluffs until the first decades of the 20th century. They still actively work to protect the many native cultural sites on the Hanford Site.

Plants with Substantial Range Extensions

Cistanthe rosea (S. Watson) Hershkovitz (Portulacaceae)

Cistanthe rosea is a small annual previously known from central Oregon to central California east of the Sierra Nevada, east to Nevada, and in the Pacific Northwest in Butte County, Idaho (Hitchcock et al. 1955–1969). It generally occurs in sagebrush desert to arid montane forest. The Hanford Site population is the first report for this species in Washington. It represents a 340 km extension of its previous northern limit in Harney County, Oregon.

In 1997, we located a total of 12 small clusters of *Cistanthe rosea* north of Gable Mountain in the central portion of the Hanford Site, in an area approximately 1.5 × 1.2 kilometers. With an estimated total of 150 plants, the population was not large. The plants were growing in flat or gently sloping areas on dark basalt-derived sand substrate within low swales in relatively dense big sagebrush. *Cistanthe rosea* grew with *Artemisia tridentata*, *Bromus tectorum*, *Descurainea pinnata* (Walter) Britt., *Loeflingia squarrosa* Nutt., and *Mimulus suksdorfii* A. Gray. *Cistanthe rosea* is currently included on the Threatened list in Washington (Washington Natural Heritage Program 2005). It occured in an area that is not formally protected from Hanford activities.

Gilia leptomeria A. Gray (Polemoniaceae)

Gilia leptomeria is known from open, sandy or rocky areas in the Great Basin and Rocky Mountain states of the North American west (Kartesz 2003). In Washington, an accurate identification of *G. leptomeria* was difficult because Hitchcock and Cronquist (1973) did not recognize that there were two expressions within the concept of *G. leptomeria*. Day (1993) segregated *G. lottiae*, a more frequently encountered gilia of the sandy shrub-steppe in eastern Washington, from *G. leptomeria*, which is primarily known from southern Oregon south through California and east to Utah. The Jepson Manual (Hickman 1993) contains a key that differentiates *G. lottiae* from *G. leptomeria*. The Hanford Site populations are the first reported for *G. leptomeria* in Washington, and our collections were confirmed by Alva Day. It represents a 340 km extension of its previous northern limit in Malheur County, Oregon.

We found *Gilia leptomeria* in a number of localities on the Hanford site, including the White Bluffs, Umtanum Ridge, north of Gable Mountain, and the gravelly bluffs north of the Columbia River in the vicinity of Vernita Bridge. The Hanford Site populations were small, at least in the years we saw them. When we surveyed them in 1995 and 1997, most of the eight populations located had 100 plants or less, for an estimated total of less than 1000 plants. We observed *G. leptomeria* growing in a variety of habitats and substrates, including basalt dunes, caliche soil, gravelly slopes, and shrub-steppe. Commonly observed associates of *G. leptomeria* included *Artemisia tridentata*, *Poa secunda*, *Bromus. tectorum* L., *Astragalus caricinus*, *Salvia dorrii*, and a number of other annual species. It was found growing with several other plants considered rare in Washington. Currently, *G. leptomeria* is included on the Threatened list for Washington (Washington Natural Heritage Program 2005). Some of the populations occurred in areas that are not formally protected from Hanford activities.

Loeflingia squarrosa Nutt. (Caryophyllaceae)

This is the first report of *Loeflingia squarrosa* for Washington. It is generally found at less than

1200 m in California and northern Baja California, and from southeastern Oregon (Hickman 1993). Our collections represent a 420 km extension of its previous northern limit near Malheur Lake and Frenchglen in Harney County, Oregon (Peck 1961).

We found *Loeflingia squarrosa* in a number of localities on the Hanford site. The eight Hanford Site populations were relatively large in the years we saw them. When we surveyed them in 1995 and 1997, we estimated a total of at least 8000 plants. At Hanford, *L. squarrosa* typically grew in flat or gently sloping areas on dark basalt derived sand substrate within low swales in relatively dense big sagebrush. One population was growing in a vernal pool on Umtanum Ridge. Commonly observed associates of *L. squarrosa* included *Artemisia tridentata*, *Poa secunda*, *Bromus tectorum*, *Cryptantha circumscissa* (Hook. & Arn.) I.M. Johnst., *Mimulus suksdorfii*, and a variety of other annual species. Currently, *L. squarrosa* is included on the Threatened list for Washington (Washington Natural Heritage Program 2005). Most populations of *L. squarrosa* occurred in areas that are not formally protected from Hanford activities.

Myosurus clavicaulis Peck (Ranunculaceae)

In 1997, we found a population of unusual *Myosurus* plants in a vernal pool on the east end of Umtanum Ridge on the Hanford Site. Plants from this site resemble *Myosurus* plants of certain vernal pool populations in coastal southern California, northern Baja California, and Harney County, Oregon. Plants from these populations share most of the morphological characteristics of *Myosurus minimus* L., but have short, curved scapes, so that the heads of the achenes are immersed in the leaves (Whittemore 1997). Since 1997, *M. clavicaulis* has been found at several additional vernal pool sites in eastern Washington by other workers (Washington Natural Heritage Program database).

Stone (1959) suggested that this form of *Myosurus* resulted from past hybridization between the two species *Myosurus minimus* L. and *M. sessilis* S. Watson. during a time when *M. sessilis* had a wider range than it does now. Currently, *M. sessilis* is not known to occur north of Umatilla Co., Oregon (Hitchcock and Cronquist 1973; Whittemore 1997). At the coastal southern California, northern Baja California, Oregon, and Washington sites, this expression occurs as a self-sustaining entity, independent of *M. sessilis* and often independent of *M. minimus*. The taxonomic status of these plants is obscured by the presence of morphologically identical plants in the Central Valley of California. The Central Valley plants are non-persistent products of on-going hybridization between *M. minimus* and *M. sessilis* (Whittemore 1997). When he examined the Hanford Site collections in 1997, Whittemore suggested that we call them *Myosurus clavicaulis* Peck to distinguish them from typical *M. minimus* and plants from *M. minimus* × *sessilis* hybrid swarms.

The Washington populations represent a more than 375 km extension of its previous northern limit in Harney County, OR. When surveyed in 1997, there were estimated to be over 1000 plants in the Hanford Site population. The population was found on the south and southeast-facing sides of the farthest west vernal pool (20 × 20 m) in a set of vernal pools on Umtanum Ridge. Plants grew on the drying edges of the pool, with *Veronica peregrina* L. ssp. *xalapensis* (Kunth) Pennell, *Camissonia andina* (Nutt.) Raven, *Myosurus apetalus* Gay, *Epilobium minutum* Lindl. ex Lehm., *Artemisia rigida* (Nutt.) A. Gray, mosses and lichens. *Myosurus clavicaulis* on the Hanford Site is self-sustaining and does not occur within close proximity of either *M. sessilis* or *M. minimus*. Currently, *M. clavicaulis* is included on the Sensitive list for Washington (Washington Natural Heritage Program 2005).

Previously Unrecognized Species

Festuca washingtonica Alexeev

In 1995, we collected an unusual *Festuca* high on the north-facing slopes of Rattlesnake Mountain in the Arid Lands Ecology Reserve (ALE). We sent this collection to B. Wilson at Oregon State University, who identified it as *Festuca washingtonica* Alexeev. The history of this taxon is as follows: in 1960, J. G. Smith collected what he called *F. rubra* L. in Peavine Canyon, Chelan County, Washington. A portion of the collection was eventually sent to Leningrad. From that lone specimen, E.B. Alexeev (1982) described *F. washingtonica*, with the note (translated from Russian) "in habit and anatomical structure of the leaf blades this species resembles *F. rubra*. However, within the limits of the very polymorphic latter species, we do not know of a single taxon with leaf blades that are externally scabrous as in *F. washingtonica*." (Alexeev 1982). Alexeev's new fescue species was largely ignored until our collections of it in 1995. Based on our collections from the Hanford Site and from other locations, B. Wilson wrote an expanded description of *F. washingtonica*, (Wilson 1999).

Festuca washingtonica is a relatively large, bright to deep green, cespitose fescue with flat leaves 1 to 6 mm wide, lemmas scabrous or pubescent, and ovary apex typically pubescent. According to Wilson (1999), "*Festuca washingtonica* differs from *F. viridula* in having closed sheaths, extravaginal shoots, and abaxial to adaxial sclerenchyma strands in the leaves, illustrated by Alexeev (1982)". *Festuca washing-*

tonica may belong in the subgenus *Festuca*, although analysis of seed proteins suggests problems with that classification (Aiken et al. 1998).

Festuca washingtonica appears to be endemic to seasonally moist habitats in deep soil of lightly grazed or ungrazed shrub-steppe communities east of the Cascade Range in Washington, including the ALE Reserve on the Hanford Site. On the ALE Reserve, plants occurred just below the top of Rattlesnake Mountain in rocky silt loam at an elevation of 1100 m. This was within an *Artemisia tripartitalFestuca idahoensis* plant association with *Lupinus arbustus* Douglas ex Lindl. ssp. *calcaratus* (Kellogg) D. Dunn, *Melica bulbosa* Geyer, *Poa cusickii* Vasey, *P. secunda* J. Presl., and *Senecio integerrimus* Nutt.

Since 1995, *Festuca washingtonica* has been collected from other counties in eastern Washington, including Yakima, Kittitas, Chelan and Okanogan Counties, suggesting that the taxon may have been overlooked and/or mis-identified by past researchers. Most sites where it grows are protected from livestock, either administratively or topographically. To our knowledge, it has not been collected outside of Washington.

Other Findings

The Hanford Site supports approximately 725 different kinds of vascular plants (Sackschewsky and Downs 2001). Of these, 29 (4%) are listed by the state of Washington as rare (Washington Natural Heritage Program 2005). During our three-year botanical inventory of the Hanford Site, we identified more than 500 species of plants and 112 populations of 26 state-listed rare plants (Soll et al. 1999). Two of these rare plants are endemic to the Hanford Site: *Physaria douglasii* subsp. *tuplashensis* and *Eriogonum codium*. Four are narrow regional endemics that also occur outside the boundaries of the Hanford Site: *Astragalus columbianus* Barneby, *A. conjunctus* var. *rickardii*, *Lomatium tuberosum* Hoover, and *Penstemon eriantherus* Pursh var. *whitedii* (Piper) A.Nelson. Four are more widespread regional endemics that are also known from elsewhere in the Columbia Basin: *Camissonia pygmaea* (Douglas ex Lehm.) Raven, *Cryptantha leucophaea* (Douglas ex Lehm.) Payson, *Erigeron piperianus* Cronquist, and *Rorippa columbiae* (Suksd. ex B.L.Rob.) Suksd. ex Howell. There are also a number of regional endemics known from the Hanford Site that are not considered rare in Washington.

Eighteen species found by the authors on the Hanford Site are widely distributed in North America but are disjunct or peripheral in Washington. These are considered rare and are tracked by the Washington Natural Heritage Program: *Ammannia robusta* Heer & Regel, *Anagallis minima* (L.) Krause, *Astragalus geyeri* A. Gray, *Camissonia minor* (A. Nelson) Raven, *Castilleja minor* (a. Gray) Gray ssp. *minor*, *C. spiculifera* (Piper) Payson, *Cistanthe rosea*, *Cryptantha scoparia* A. Nelson, *Cuscuta denticulata* Engelm. var. *denticulata*, *Cyperus bipartitus* Torr., *Eatonella nivea* (D.C. Eaton) A. Gray, *Gilia leptomeria*, *Hypericum majus* (Gray) Britt., *Lipocarpha aristulata* (Covill) G.C. Tucker, *Loeflingia squarrosa*, *Mimulus suksdorfii* Gray, *Myosurus clavicaulis* Peck, *Oenothera caespitosa* Nutt., and *Rotala ramosior* (L.) Koehne. *Festuca washingtonica* is abundant enough state-wide that it is not tracked by the Washington Natural Heritage Program.

Discussion and Conclusion

The findings of the botanical portion of the Hanford Biodiversity Project have reinforced the importance of the Hanford Site for conservation of shrub-steppe vascular plants. The very high plant species richness of the Hanford Site is likely the result of a combination of geographic and historical factors. The Columbia River corridor, which bisects the Hanford Site, is known to support a large number of regional and narrow endemics (Hitchcock and Cronquist 1973). The Hanford Reach, the only undammed portion of the Columbia River, supports emergent wetland communities that include populations of several rare species that were once widely collected but are now uncommon elsewhere on the river (Soll et al. 1999). In addition, the unique climate of the Hanford Site supports a number of species that are more common in desert areas of the Great Basin to the south and east (Kartesz 2003). The diversity of unique substrates and habitats on the Site provide habitat for a large number of state-listed rare plants and endemics, including those reported above.

Much of the biodiversity of the Hanford Site might have been lost without its unique history. If the Hanford Site had not been acquired by the U.S. Government in 1943, it would most certainly resemble the rest of the lower Columbia Basin where population growth, large-scale irrigation projects, livestock grazing, and noxious weeds have significantly reduced and/or degraded available habitat for many plants. The relatively large Hanford Site, taken with the similar sized Department of Defense Yakima Training Center to the west, constitute the largest remaining blocks of relatively undisturbed shrub-steppe in the Columbia Basin Ecoregion (Soll et al. 1999).

Of the state-listed rare plants found on the Hanford Site, 18 (62%) are annuals, and 3 of these have not been found elsewhere in Washington. Because of the relatively high number of rare annuals on the Hanford Site, it is an important location for the conservation of rare annuals in Washington. Annuals tend to occur in

TABLE 1. SUMMARY OF ADDITIONS TO THE VASCULAR FLORA OF WASHINGTON FROM THE HANFORD BIODIVERSITY PROJECT.

Species	Previously known range	Washington counties where currently known	Washington Natural Heritage Program status (2005)
Astragalus conjunctus var. *rickardii*	Not known	Benton	Watch
Cistanthe rosea	Oregon, California, Idaho, Nevada, Wyoming	Benton	Threatened
Eriogonum codium	Not known	Benton	Endangered
Festuca washingonica	Chelan County, Washington	Benton, Yakima, Kittitas, Chelan, Okanogan	None
Gilia leptomeria	California, Oregon, Idaho, Colorado, New Mexico, Arizona, Nevada, Wyoming, Montana	Franklin, Grant, Benton	Threatened
Physaria douglasii subsp. *tuplashensis*	Not known	Franklin	Threatened
Loeflingia squarrosa ssp. *squarrosa*	Western states not including Pacific NW	Benton	Threatened
Myosurus clavicaulis	California, Oregon	Adams, Spokane, Benton	Sensitive

moist microhabitats in open sandy or gravelly soils, and many of these sites elsewhere in the state have been disturbed and compacted by grazing and invaded by *Bromus tectorum*.

At the time that the Hanford Biodiversity Study began, the conservation of the biodiversity of the Hanford Site was not assured. There was a powerful local movement to distribute most of the land north of the Columbia River to private landowners for agricultural development. The future protection of the ALE Reserve was also in question. Since that time, the Hanford Reach has been declared a Wild and Scenic River and much of the Hanford Site, including the ALE Reserve, has been set aside as the Hanford Reach National Monument. However, the central portion of the Site, which supports a number of rare plant populations, is still primarily dedicated to nuclear waste storage and clean-up. The *Eriogonum codium* population, although formally within the Hanford National Monument, is not in an area currently managed by the USFWS.

Even with protection, active, on-going management will be necessary to maintain the biodiversity of the Hanford Site. In particular, noxious weeds (e.g., *Bromus tectorum* L., *Salsola kali* L., *Centaurea solstitialis* L. and others) and wildfire will bring adverse changes to natural vegetation communities over time. Nonetheless, the future of the vascular plant diversity of the Hanford Site appears considerably better than it did in 1994, when the Hanford Biodiversity Project was initiated.

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LITERATURE CITED

AIKEN, S. G., S. E. GARDINER, H. C. M. BASSETT, B. L. WILSON AND L. L. CONSAUL. 1998. Implications from SDS-PAGE analyses of seed proteins in the classification of taxa of *Festuca* and *Lolium* (Poaceae). Biochemical Systematics and Ecology 26:511–533.

ALEXEEV, E. B. 1982. New and little-known fescues (*Festuca* L.) of North America. Bjulleten Moskovskogo Obščestva Ispytatelej Prirody, Otdel Biologičeskij [Bulletin of the Moscow Society of Naturalists, Biological Division] 87(2): 109–118.

AL-SHEHBAZ, I. AND S. O'KANE. 2002. *Lesquerella* is untied with *Physaria* (Brassicaceae). Novon 12:319–329.

BAER (NORTHERN STATES BURNED AREA EMERGENCY REHABILITATION) TEAM. 2000. 24 Command Fire burned area emergency rehabilitation (BAER) plan. United States Department of the Interior, Washington DC.

BARNEBY, R. C. 1964. Atlas of North American *Astragalus*. Memoirs of the New York Botanical Garden 13:1–1188.

DAUBENMIRE, R. 1970. Steppe vegetation of Washington. Washingon State Agricultural Experiment Station, Technical Bulletin 62:1–131.

DAY, A. G. 1993. New taxa and nomenclatural changes in *Allophyllum*, *Gilia*, and *Navarretia* (Polemoniaceae). Novon 3:331–340.

DOWNS, J. L., W. H. RICKARD, C. A. BRANDT, L. L. CADWELL, C. E. CUSHING, D. R. GEIST, R. M. MAZAIKA, D. A. NEITZEL, L. E. ROGERS, M. R. SACKSCHEWSKY AND J. J. NUGENT. 1993. Habitat types on the Hanford Site: wildlife and plant species of concern. PNL-894, Pacific Northwest National Laboratory, Richland, WA.

Dunwiddie, P. W., K. A. Beck and F. E. Caplow. 2001. Demographic studies of *Eriogonum codium* in Washington. Pp. 59–69 *in* S. H. Reichard, P. W. Dunwiddie, J. Gamon, A. R. Kruckeberg, and D. L. Salstrom (eds.), Conservation of Washington's rare plants and ecosystems. Washington Native Plant Society, Seattle, WA.

Franklin, J. F. and C. T. Dyrness. 1973. Natural vegetation of Oregon and Washington. General Technical Report PNW-8, U.S. Forest Service, Portland, OR.

Goff, F. E. 1981. Preliminary geology of eastern Umtanum Ridge, south central Washington. RHO-BWI-C-21, Rockwell Hanford operations, Richland, WA.

Gray, A., S. Watson and B. L. Robinson. 1895. Synoptical flora of North America I pt. I, Fascicles 1. Polypetalae from the Ranunculaceae to the Frankeniaceae. Continued and edited by Benjamin Lincoln Robinson. Ivison, Blakeman, Taylor, and Co., New York, NY.

Hickman, J. C. (ed.). 1993. The Jepson manual: higher plants of California. University of California Press, Berkeley, CA.

Hitchcock, C. L., A. Cronquist, M. Ownbey and J. W. Thompson. 1955–1969. Vascular plants of the Pacific Northwest. University of Washington Press, Seattle, WA.

——— and A. Cronquist. 1973. Flora of the Pacific Northwest: an illustrated manual. University of Washington Press, Seattle, WA.

Integrated Taxonomic Information System online database. Available at: http://www.itis.usda.gov. Accessed: December 12, 2005.

Kartesz, J. T. 2003. A synonymized checklist and atlas with biological attributes for the vascular flora of the United States, Canada, and Greenland, 2nd ed. *In* J. T. Kartesz and C. A. Meacham (eds.), Synthesis of the North American flora, Version 2.0. J.T. Kartesz & Phylosystems Corp., Richmond, CA.

Nature Conservancy of Washington. 1998. Biodiversity inventory and analysis of the Hanford Site 1997 annual report. The Nature Conservancy of Washington, Seattle, WA.

Newcomb, R. C. 1958. Ringold Formation of the Pleistocene Age in type locality: the White Bluffs, Washington. American Journal of Science 256:328–340.

Pacific Northwest National Laboratory. 1997. Climatological data, Hanford Meteorology Station. Pacific Northwest National Laboratory, Richland, WA. Available at: http://etd.pnl.gov:2080/HMS/.

Payson, E. B. 1922. A monograph of the genus *Lesquerella*. Annals of the Missouri. Botanical Garden 8:103–236.

Peck, M. E. 1961. A manual of the higher plants of Oregon. Oregon State University Press, Portland, OR.

Piper, C. V. 1906. Flora of the State of Washington. Contributions of the U.S. National Herbarium 11:1–637.

Reveal, J. L., F. Caplow and K. Beck. 1997 [1995]. *Eriogonum codium* (Polygonaceae: Eriogonoideae), a new species from southcentral Washington. Rhodora 97:350–356.

Rollins, R. C. 1993. The Cruciferae of Continental North America. I–XVI, 1-976. Stanford University Press, Stanford, CA.

——— and E. C. Shaw. 1973. The Genus *Lesquerella* (Cruciferae) in North America. Harvard University Press, Cambridge, MA.

———, K. A. Beck and F. E. Caplow. 1996 [1995]. An undescribed species of *Lesquerella* (Cruciferae) from the state of Washington. Rhodora 97:201–207.

Rose, J. N. 1904. William M. Canby, Botanical Gazette 37:385–387.

Sackschewsky, M. R. and J. L. Downs. 2001. Vascular plants of the Hanford Site. PNNL-13688, Pacific Northwest National Laboratory, Richland, WA.

Soll, J., J. A. Hall, R. Pabst and C. Soper. 1999. Biodiversity inventory and analysis of the Hanford Site Final Report: 1994–1999. The Nature Conservancy of Washington, Seattle, WA.

Stone, D. E. 1959. A unique balanced breeding system in the vernal pool mouse-tails. Evolution 13:151–174.

U.S. Fish and Wildlife Service. 1999. Endangered and threatened wildlife and plants; review of plant and animal taxa that are candidates or proposed for listing as endangered or threatened; notice of review. Federal Register 64(205): 57534–57547.

Washington Natural Heritage Program. 1994. Endangered, threatened and sensitive vascular plants of Washington—with working lists of rare non-vascular species. Department of Natural Resources, Olympia, WA.

Washington Natural Heritage Program. 2005. List of plants tracked by the Washington Natural Heritage Program. Available at: http://www.dnr.wa.gov/nhp/refdesk/lists/plantrnk.html.

Welsh, S. L., F. Caplow and K. Beck. 1997. New variety of *Astragalus conjunctus* S. Watson from Benton County, Washington. Great Basin Naturalist 57:352–354.

Whittemore, A. T. 1997. *Myosurus* Linnaeus, Sp, Pl. 1:2284. 1753; Gen. Pl. ed. 5, 137. 1754. Flora of North America 3:135–138.

Wilson, B. L. 1999. *Festuca* taxonomy in the Pacific coast states. Unpublished Ph.D. thesis. Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR.

Appendix 1

Relevant Herbarium Collections by the Authors of Rare Plants on the Hanford Site

Astragalus conjunctus var. *rickardii* Welsh, K.A. Beck & Caplow (FABACEAE). TYPE: U.S.A., Washington, Benton Co. Hanford Site, on northeast-facing slopes of Rattlesnake Mountain, with *Artemisia tridentata*, *Poa sandbergii*, 1036 meters, T11N R26E sect. 30 NW¼ of SW¼, 29 May 1995, *Kathryn Beck & Florence Caplow 95-083*, (Holotype: BRY!; Isotypes: NY!, US!, WTU!, WS!); Benton County, Horse Heaven Hills, Chandler Butte, BLM owned, in silt loam, upper north-facing slopes, with *Agropyron spicatum*, *Poa cusickii*, *Artemisia tridentata*, *Poa sandbergii*, 600 meters, T9N R26E sect. 22 SE¼ of NW¼, 14 April 1995, *Florence E. Caplow & Kathryn A. Beck 95-022* (BRY, WTU).

Cistanthe rosea S. Watson (PORTULACACEAE). Benton Co., Hanford Site north of Gable Mountain in basalt derived sands, in a small swale, with *Artemisia tridentata*, *Bromus tectorum*, *Descurainea pinnata*, *Loeflingia squarrosa* ssp. *squarrosa* and *Mimulus suksdorfii*, 1–2% slope, south exposure, 150 meters, T13N R26E sect. 2 SE¼ of S½, 28 May 1995, *Florence E. Caplow & Kathryn A. Beck 95-078* (WTU).

Eriogonum codium Reveal, Caplow & K.A. Beck (POLYGONACEAE). TYPE: U.S.A., Benton Co., Hanford Site, on the northern edge of Umtanum Ridge west of Washington Highway 24 overlooking the Columbia River about 38 air miles northwest of Richland, on volcanic soil, with *Grayia spinosa*, *Artemisia tridentata*, *Salvia dorrii*, *Hesperostipa comata*, and *Pseudoroegneria spicata*, 350 meters, T13N R24E sect. 13, 27 June 1995, *Reveal, Caplow and Sackschewsky 7484* (Holotype: US; Isotypes: BM, BRY, CAS, COLO, GH, K, MARY, MO, NY, RM, RSA, TEX, UC, WS, WTU and elsewhere); Also in reddish to black, hard-packed basalt gravel, with *Artemisia tridentata*, *Salvia dorrii*, *Poa sandbergii*, *Bromus tectorum*, *Phacelia linearis*, 300°, 3% slope, T13N R24E sect. 13 NE¼ of SW¼, 31 May 1995, *Florence E. Caplow & Kathryn A. Beck 95-084* (WTU, WS).

Festuca washingtonica E.B.Alexeev (POACEAE). Benton Co., Arid Lands Ecology Reserve, Hanford Site, Rattlesnake Mountain, in a narrow strip just below the top of the mountain, in the "snowmelt" zone, in rocky silt loam, with *Artemisia tridentata*, *Lupinus laxiflorus* var. *calcaratus*, *Poa nevadensis*, *Senecio integerrimus*, *Festuca idahoensis*, *Melica bulbosa*, and *Poa cusickii*, 45°, 35%, 1130 meters, T11N R26E sect. 30 NW¼ of SW¼, 4 June 1995, *Florence E. Caplow & Kathryn A. Beck 95088* (OSU, WTU); Chelan Co., Wenatchee National Forest, Wenatchee Mountains, on lower west-facing dry slopes of a small tributary in Peavine Canyon, with *Pinus ponderosa*, *Symphoricarpos albus*, *Salix* sp., *Acer douglasii*, *Prunus emarginata*, *Purshia tridentata*, *Lupinus leucophyllus*, *Aster foliaceus*, *Agropyron spicatum*, and *Poa pratensis*, 270°, 5%, 630 meters, T22N R19E sect. 15 SW¼ of SE¼, *Kathryn A. Beck & Florence E. Caplow 96-052* (OSU, WTU).

Gilia leptomeria A. Gray (POLEMONIACEAE). Grant Co., Hanford Site, Saddle Mountain NWR, on upper slopes of gravelly bluff north of Vernita Bridge on the Columbia River, with *Salvia dorrii*, *Camissonia pygmaea*, and *Eatonella nivea*, south exposure, 30%, 215 meters, T14N R25E sect. 31 SE¼, 15 May 1995, *Florence E. Caplow & Kathryn A. Beck 95-035* (WTU); Franklin Co., Hanford Site, Wahluke Wildlife Area, White Bluffs of the Columbia River, near top of bluffs, in caliche soil, with *Eriogonum microthecum*, *Poa secunda*, *Bromus tectorum*, *Astragalus caricinus*, and *Eurotia lanata*, western exposure, 285 meters, T13N R27E sect. 25, 19 May 1995, *Florence E. Caplow & Kathryn A. Beck 95-055* (WTU); Also on sparsely vegetated ground in sand and caliche, with *Chrysothamnus nauseosus*, *Bromus tectorum*, *Astragalus caricinus*, *Artemisia tridentata*, *Astragalus succumbens*, and *Gilia sinuata*, 220°, 5%, T13N R28E sect. 19 SE¼ of NW¼, 31 May 1997, *Florence E. Caplow & Kathryn A. Beck 97-042* (WTU); Benton Co., Hanford Site Umtanum Ridge, ridge-top, at edges of steep north-facing slopes, in fine reddish to blackish basalt, gravel and pumice, with *Artemisia tridentata*, *Eriogonum codium*, *Bromus tectorum*, *Poa secunda*, and *Salvia dorrii*, 350 meters, T13N R24E sect. 13 NE¼ of SW¼, 31 May 1995, *Florence E. Caplow & Kathryn A. Beck 95-076* (WTU); Additional unvouchered populations were located. Plants were determined by Alva Day, 1995.

Physaria douglasii subsp. *tuplashensis* Rollins, K.A. Beck & Caplow (BRASSICACEAE). TYPE: U.S.A. Washington, Franklin County: White Bluffs, above the Columbia River, caliche soil at edge of eroding bluff, with *Artemisia tridentata*, *Astragalus caricinus*, *Cryptantha spiculifera*, *Eriogonum microthecum*, and *Poa sandbergii*, T13N R27E sect. 11 W1/2, 20 July 1994, *Kathryn A. Beck & Florence Caplow 94-001* (Holotype: GH; Isotype: WTU). Franklin Co., Hanford Site, Wahluke Wildlife Area, White Bluffs northeast of the Columbia River, near powerlines, on the leading edge of the bluffs, in hard caliche soils, with *Poa secunda*, *Astragalus caricinus*, *Cryptantha spiculifera*, *Eriogonum microthecum* var. *laxiflorum*, 300 meters, T13N R27 E sect. 24 NE¼ of NE¼, 19 May 1995, *Florence E. Caplow & Kathryn A. Beck 95-053* (WTU, GH). Upper slopes near mouth of Ringold Canyon, in loose caliche soils, with *Poa secunda*, *Bromus tectorum*, *Amsinckia tessellata*, 220 meters, T12N R28E sect. 11 NW¼ of SW¼, 1 June 1995, *Florence E. Caplow & Kathryn A. Beck 95-086* (GH).

Loeflingia squarrosa Nutt. ssp. *squarrosa* (CARYOPHYLLACEAE). Benton Co., Hanford Site, north of Gable Mountain in basalt-derived, stabilized sand dunes, on a sandy berm of a little-used road, with *Artemisia tridentata*, *Poa secunda*, *Bromus tectorum*, *Cryptantha circumcissa*, and *Mimulus suksdorfii*, 145 meters, T13N R26E sect. 13, 16 May 1995, *Florence E. Caplow & Kathryn A. Beck 95-039* (WTU); Benton Co., Hanford Site, between two main portions of Gable Butte, in shrub-steppe at edges of vernal pool in rocky basalt layer, with *Artemisia tridentata*, *Gnaphalium palustre*, *Camissonia andina*, *Juncus bufonius*, *Epilobium minutum*, moss spp., and lichen spp., 175 meters, T13N R26E sect. 18 SW¼ of SW¼, 20 May 1997, *Florence E. Caplow & Kathryn A. Beck 97-023* (WTU); also south of Gable Mountain, plants growing in shrub-steppe, in barren basalt-derived sand, along a little-used sandy road, with *Artemisia tridentata*, *Ambrosia acanthicarpa*, *Pectocarya linearis*, *Bromus tectorum*, and *Mimulus suksdorfii*, 160 meters, T13N R26E sect. 25 SE¼ of NE¼, 29 May 1997, *Florence Caplow & Kathryn A. Beck 97-041* (WTU). Plants were verified by Ronald Hartman, 1995. Additional unvouchered populations were located, including ones at the eastern end of Umtanum Ridge, in a vernal pool and also in a swale amidst shrub-steppe.

Myosurus clavicaulis Peck (RANUNCULACEAE). Benton Co., Hanford Site, top of east end of Umtanum Ridge, plants growing on dried edges of vernal pool in depression of basalt layer, with *Veronica peregrina* var. *xalapensis*, *Camissonia andina*, *Myosurus apetalus*, *Epilobium minutum*, *Artemisia rigida*, moss spp., and lichen spp., 315°, 1% slope, 195 meters, T13N R25E sect. 17 ¼ of ¼, 6 May 1997, *Florence E. Caplow & Kathryn A. Beck 97-010* (US, WTU); same location, 7 May 1997, *Florence E. Caplow & Kathryn A. Beck 97-014* (WTU), verified by Alan Whittemore.